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REMARKS

A Substitute Specification is being filed separately.

The claims are amended above to attend to the objections under 35 USC 112, second paragraph. However, the binding of hydrogen is understood in the art of making a SOI structure.

Claim 1 is now in Jepson or improvement form to traverse the rejections under 35 USC 103 from the cited Chan and Okuchi, et al. patents in two ways.

First, it confirms that the claimed method is a method of making a SOI structure.

> Any terminology in the preamble that limits the structure of the claimed invention must be treated as a claim limitation. *MPEP* 2111.02.

Therefore, while the Action admits that the Chan patent fails to teach drying a SOI structure in a vacuum and cites the Okuchi, et al. patent for vacuum drying, the Okuchi, et al. patent does not disclose or suggest a method of making a SOI structure, as claimed. There is no reason for the combination, therefore, except hindsight from the claims, which is improper for a rejection.

Second, while the Okuchi, et al. patent discloses vacuum drying as indicated in the Action, it neither discloses nor suggests the second improvement of claim 1, that the vacuum is also used for joining. As the Chan patent fails entirely to disclose vacuum, as admitted in the Action, the two references together cannot disclose or suggest the vacuum joining improvement of claim 1 and, thus, the other dependent claims.

The Chan patent teaches a process for implantation from a plasma source, and the Okuchi, et al. patent, that of drying silicon wafers in vacuum. The claimed invention teaches a hydrophilic bonding process whose mechanism has not been investigated to the very end at

the present time and is widely discussed in the leading scientific journals (see, for instance, in reference [1] below).

It is believed that the hydrophilic surfaces of silicon in the atmosphere are covered with a layer of water whose thickness depends on the atmospheric humidity [2]. And, it is just this layer of water that ensures adhesive joining of wafers (due to a capillary effect) at the first step of hydrophilic bonding. Thus, the presence of a water layer is a critical condition for direct hydrophilic joining of wafers [3].

The key aspect of the claimed invention and its substance reside in that it teaches a «dry hydrophilic bonding» process carried out at higher temperatures in the sense that there is no physically adsorbed water on the surface of wafers at the moment of their joining, i.e., the invention teaches exceptionally important parameters of the process of bonding, which have been discussed neither by Chan nor by Okuchi. In all the examples that are known to the applicant, hydrophilic bonding is carried out in two steps: joining of wafers in the air or under vacuum at a room temperature (prebonding), and then annealing thereof at a higher temperature (150-550??) (bonding). In the present application, it has been proposed to carry out all the processes under vacuum and in a single step at a higher temperature (80-350°C).

Such a process results in a higher energy of bonding (2.0 to 2.5 J/m^2, which approaches the tension energy limit of three-dimensional silicon that ranges from 2.5 to 3.0 J/m^2), thus ensuring a transfer of the silicon layer by rupturing a hydrogen-weakened internal plane in one of the wafers. The desired result is attainable due to removing physically adsorbed water from the hydrophilic surface by way of drying under vacuum and at higher temperatures, while retaining dissociated portion of water, and namely, hydroxylic groups OH, on the surface of wafers. The presence of only these groups ensures the required energy

of bonding and absence of not only the dust, as taught by Okuchi, but also of gas filled pores, as in a conventional hydrophilic joining.

The Chan's patent teaches only a process of implantation from a plasma-immersion source, but all the subsequent operations of producing silicon-on-insulator (SOI) structures by a hydrogen transfer method are discussed therein only as those of general knowledge or already patented ones, such as, for instance, a Smart Cut method (see, the Michael Bruel patent 5,374,564 of record). A layer of silicon alone can be transferred by hydrogen only if a high energy of implantation of ions, >100 keV, and/or a high energy of bonding, ~ 2,0 J/m^2, are available, but this is possible under conditions described by Chan only in case when use is made of plasma treatment prior to joining the wafers. Otherwise, hydrogen will diffuse towards the splicing interface (at ~ 450 to 550°C), fill the gas pores that exist there, and break off the layer thus being transferred, as it has been found out experimentally, and this has become a stimulating motive for developing the technology of «dry hydrophilic bonding». Thus, the Chan patent together with Michael Bruel patent fails to ensure attaining the results now claimed.

Accumulation of hydrogen diffusing towards this interface can be avoided either by providing a diffusion barrier in the form of silicon dioxide, as in the main embodiment of the original Smart Cut method or, else, by introducing a procedure of plasma cleaning prior to bonding, as in the Farrens publications (see, for instance, in reference [4]) and her patents. The present application teaches a new - the third - method of solving this problem.

The persons skilled in the field of treating a surface under vacuum or in the field of bonding know quite well that hydroxylic groups OH and also chemically or physically adsorbed layers of water do exist on a hydrophilic surface of solid body (see, for instance, in

reference [2]). Simple drying under vacuum at temperatures about the room temperature is inefficient, since physically adsorbed water gets frozen under vacuum and, practically, it does not evaporate. By heating up to 150°C (or to a lower temperature, but during a longer time period), it is possible to remove the physically adsorbed layer. In this case, there remains a layer of water molecules, which is linked chemically by means of hydrogen links to the hydroxylic groups. Drying under vacuum at temperatures of up to 500°C, as it is taught, for instance, by Okuchi, not only removes the particulates and physically adsorbed water, but also leads to a loss in hydrophility of wafers and to a subsequent adsorption of gases (H, N, O) and hydrocarbons CH onto the surface. As a result, the energy of bonding for such wafers is lower than the critical value of 0,5 J/m^2 - a factor which does not allow to carry out a transfer of the entire layer (over the surface thereof) by shearing it off along a hydrogen-weakened plane because of accumulation of the diffusing hydrogen in the pores at the splitting interface. The substance of the present application consists in providing a method allowing to remove all the absorbed water and preserve hydroxility of the surface in order to ensure the energy of bonding that is much higher than the tension energy limit (~ 1.5 J/m^2) for an internal silicon plane weakened by hydrogen links. According to the present application, this critical parameter is ensured by selecting appropriately the conditions for joining/drying/splitting in a single step at temperatures of 300 to 400°C, but not higher than these. It is impossible to attain the same result by combining all the patents mentioned by the Examiner because of the fact that micropores are formed at the joining interface. The scientists from France, Belgium and Germany who attempted to reproduce the method thus proposed have confirmed this.

As of the filing date of the present application, the Applicant was unaware of any information about preserving a necessary hydrophility for a surface to ensure high-quality

bonding without pores as a result of heating the wafers under low vacuum (10^1-10^4 Pa). There was an example of heating the wafers joined at a room temperature and under a low vacuum [5]. Also, it was known that heating of the joint up to temperatures higher than 400°C under high vacuum (10^{-9} to 10^{-3} Pa) removes completely the adsorbed water and light hydrocarbons [3]. In order to remove heavy hydrocarbons, temperatures of higher than 700°C are required. Only in this case, bonding under vacuum gives results acceptable for semiconductor structures, without pores at the splicing interface [6]. Unfortunately, no publications have been made throughout the world as yet, wherefrom it would directly follow how a water coating varies on the surface of a silicon wafer, depending on the partial pressure of water vapours and on the temperature of a wafer under vacuum. In 2003, after the present application had been already filed, a publication [7] appeared where the authors discussed heating under vacuum at 150°C. According to the above publication, the energy of binding was found to be 1.5 lower than in case of joining under the atmospheric pressure. It was approaching its critical value of 0,5 J/m^2, but the Applicant explains this by the annealing time being insufficient under those conditions. The Applicant would like to point out that it possesses equipment that has allowed carrying out such investigations of this problem. Thus, according to IR-absorption data, less than one-fourth of a water monolayer remains on silicon wafers under the conditions of joining that are mentioned in the present application. At temperatures of up to 400°C, the wafers loose their hydrophility. That is why the Applicant has named the presently disclosed process as «dry hydrophilic bonding».

The data received by the Applicant is supported also by some later indirect references. Thus, Fig.5 in the V. Dragoj's publication [8] shows that heating of the wafers under vacuum does not vary the joining force after plasma treatment. Unfortunately, he did not raise the

temperature higher than 250°C, and he did not make a control experiment simply with a hydrophilic surface without plasma treatment, although in publication [9], where he is mentioned as a co-author, it is pointed out (Table 1) that, when bonding directly a pair of Si-Si wafers under vacuum at a temperature of 200 to 400°C, use is made of H_2O as the main degassing element. Together with him, the authors of the present invention have carried out experiments at 120°C and 400°C and obtained a lower energy of joining the wafers than at the optimum value of 350°C, this being in compliance with the results reported in publication [9] as well. Apparently, there is no data at all on bonding a Si-SiO_2 or SiO_2-SiO_2 pair under the optimum conditions of low vacuum and higher temperatures of 300 to 350°C as established by the authors. This means that the authors were a success not only in determining the critical temperature range ensuring the absence of gas filled pores at the splicing interface but also in providing an original single-step process ensuring a high energy of joining and, as a consequence, obtain high-quality SOI wafers by transferring a silicon layer alone. The competing technology of plasma activation of a surface requires high-cost plasma chambers and comprises one technological operation more; hence, it makes production of SOI structures more expensive. Besides, the known technology fails to guarantee the absence of gas filled pores after transferring and annealing [10] and, hence, the required high quality of SOI, as it has been conformed recently by the authors in a comparative experiment.

The above references are:

References

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Low-temperature processing is important for bond and exfoliation and materials integration techniques. Of particular importance for hydrophilic wafer bonding is the reduction and removal of thermally generated voids at the bond interface, i.e., voids not caused by particulates. Possible causes of thermally generated voids are excess water and hydrocarbon contamination, both at the bond interface. Several bonding preparation techniques were explored, and the effects on interfacial void density and bond strength were recorded. After bonding, all wafer pairs were annealed to 250 degrees C. Infrared imaging was used to monitor void formation, and bond strength was measured using the blade insertion method. Microvoids with lateral dimensions greater than 30 mm were imaged using acoustic microscopy. The highest bond strength was 1260 mJ/m2 for plasma-cleaned wafers followed

closely by 1150 mJ/m2 for an HF oxide strip before hydrophilization. In addition to these techniques, bonding in a vacuum or the use of a prebond anneal were able to eliminate interfacial voids up to the anneal temperature. Good results were obtained 0.88 at RT and 0.57 J/m2 only after 150oC vacuum bonding in EVG501 completely without voids. But the energy of bonding was essentially lower than in plasma activated bonding. This is not good for only silicon layer transfer during hydrogen-induced exfoliation.

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Reconsideration and allowance are, therefore, requested.

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